2017

Introduction to Water Resources Systems - University of Colorado Boulder

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Course Introduction

CVEN 5393: Water Resources Systems and Management, Spring 2017

Prof. Joseph Kasprzyk

Topic 1

About your professor

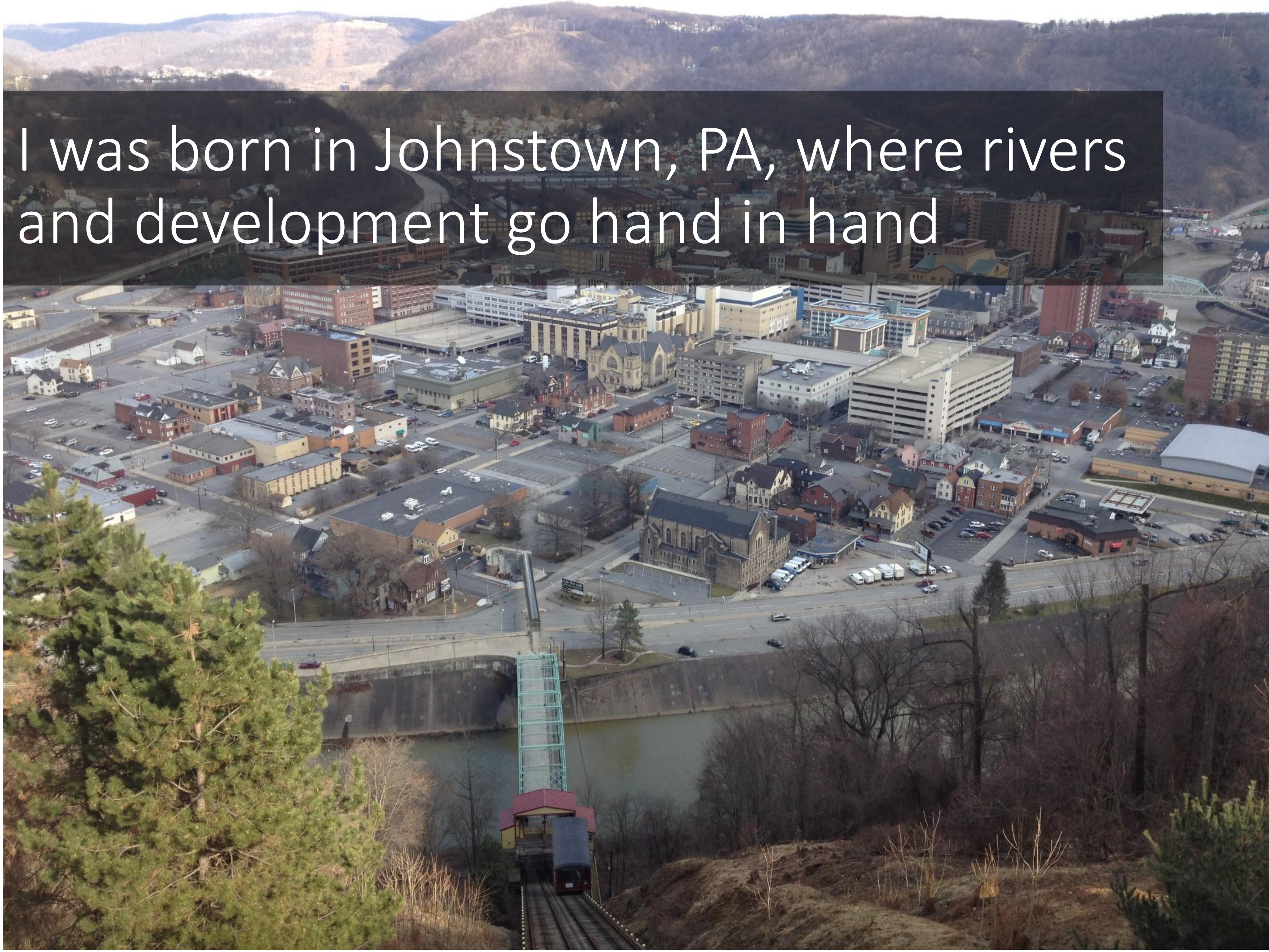
- Dr. Joseph Kasprzyk (pronounced: Kas – pry – zick)
- Graduated from Penn State University BS (2007) MS (2009) PhD (2013)
- Assistant Professor at University of Colorado since Fall 2013
- In my research, I use computer models and optimization to balance conflicting objectives for engineering design and water supply problems.
- I enjoy horseback riding, hiking, playing music
- Meet my cat!

This is a version of the Spring 2017 lecture with some logistical information removed. Contact us if you're interested in learning more about course specifics!

Outline and Learning Goals

- Some motivating examples
  - **Define** Integrated Water Resources Management
- Multi-objective decision support research in the Front Range of Colorado
  - **Explain** relevant issues that are important for water management
  - **Identify** how RiverWare simulation and optimization can be used to develop plans
- Hydrologic modeling and simulation techniques
  - **Use** the simple HyMod model to perform rainfall-runoff modeling (Assignment 1)
  - **Generate** random parameter samples and **understand** how parameter uncertainty affects model results

I was born in Johnstown, PA, where rivers and development go hand in hand



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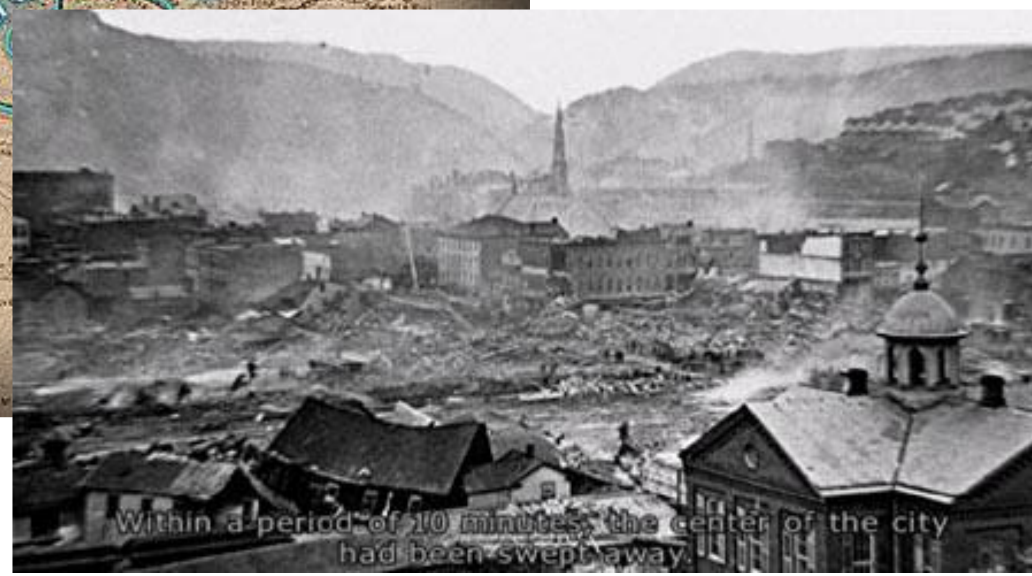
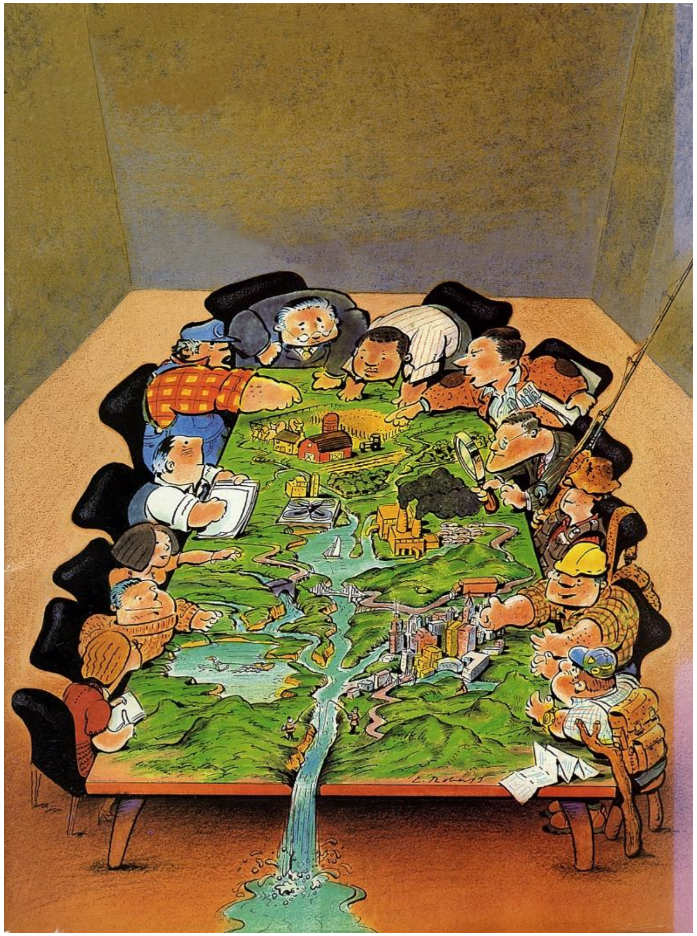


A series of floods in the late 1800's and early 1900's caused the **1936 Flood Control Act** to be passed. This shows that disasters often cause new or revised water resources *regulations*.

In 1977, Johnstown saw 6-12 inches of rainfall over a 6-8 hour period. 7 dam failures led to 78 deaths and $300 million in damage.

Scarcity is another motivating factor for water resources management.

- Water resources systems analysis borrows from **economics** for these problems, since economics is the study of allocation of scarce resources.
- In a situation with water shortage, planners must determine:
    - How much water is projected to be available in the future?
    - Who benefits most from using water at a given time and location?
    - How should the benefits of a water project be spread throughout a basin?



Overall, water resources management aims to **increase water security.**

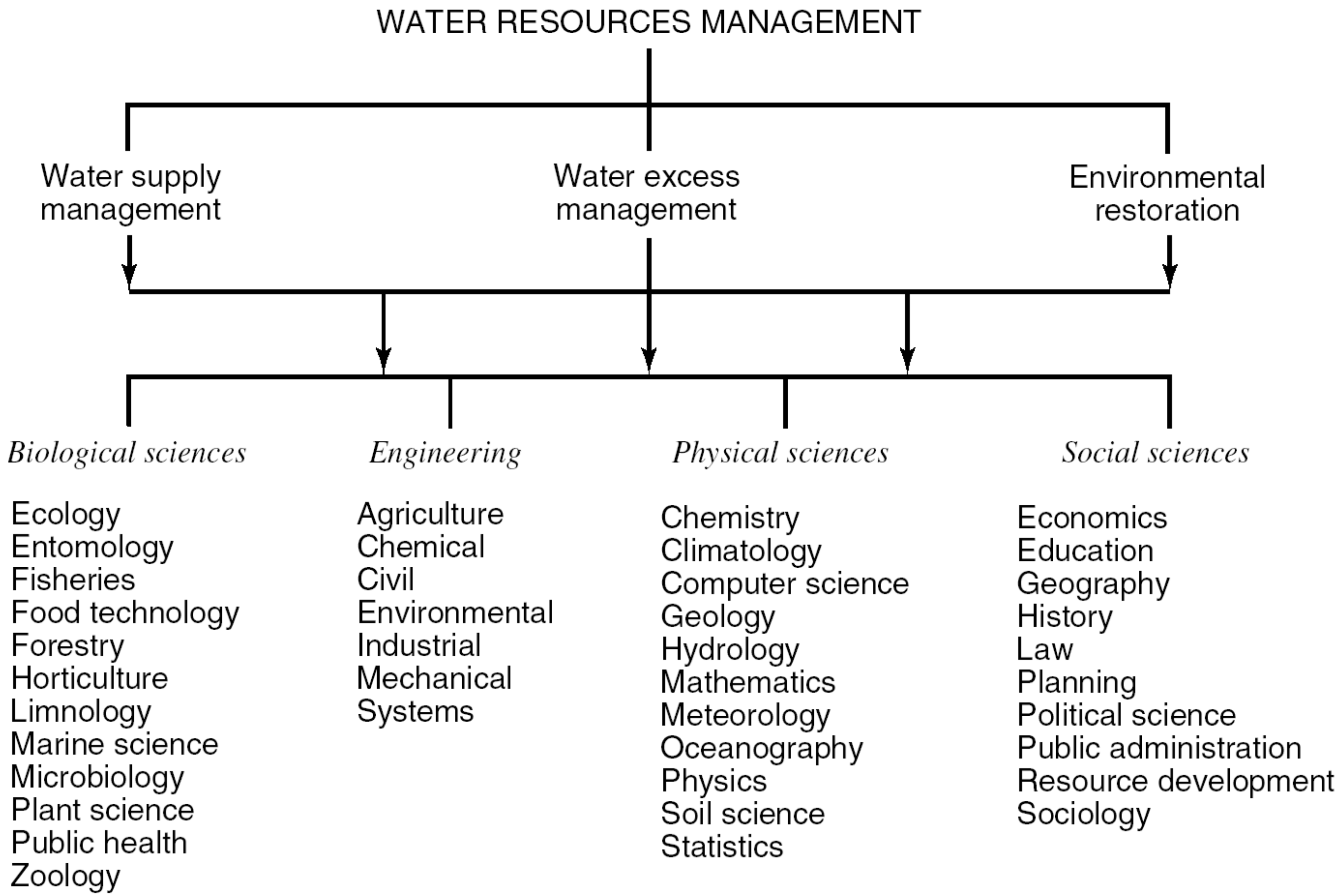


Figure 1.1.1 (p. 1)
Ingredients of water resources management (from Mays, 1996).

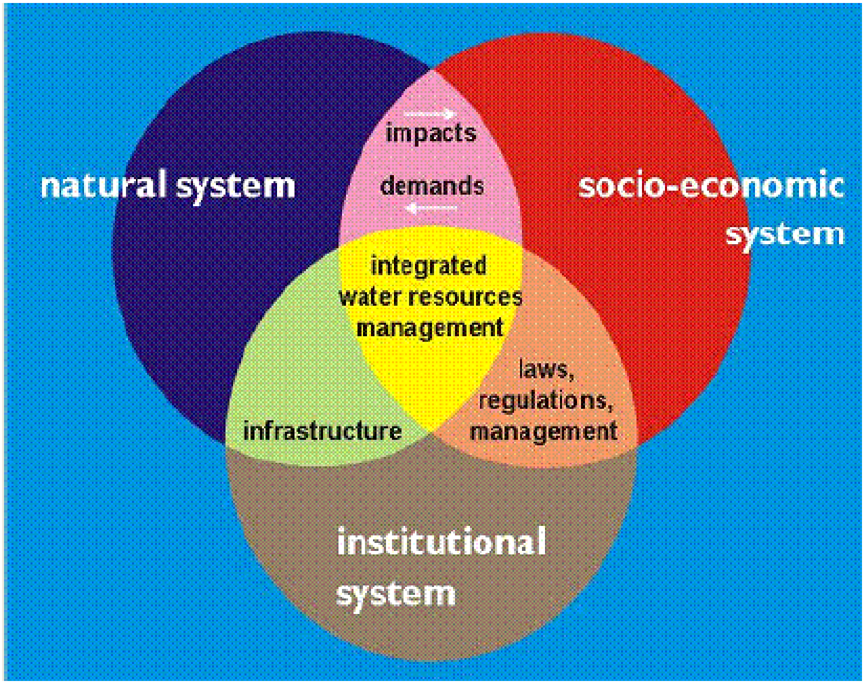
Water Resources Management, 2005 Edition by Larry W. Mays

Integrated Water Resources Management (IWRM)

Box 1.2. Definition of IWRM

IWRM is a *process* which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant *economic and social welfare* in an equitable manner without compromising the *sustainability of vital ecosystems*.

(GWP, 2000)



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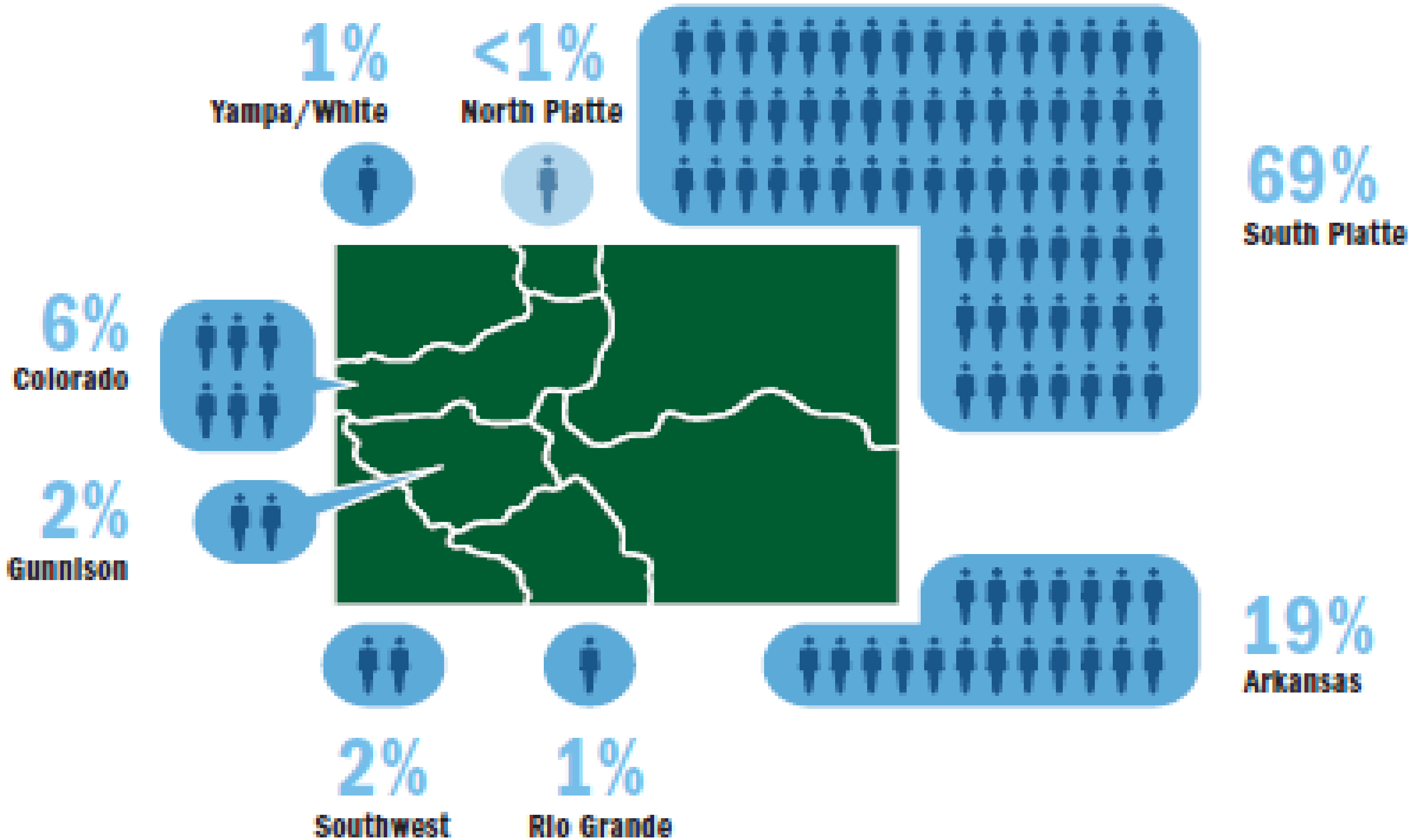
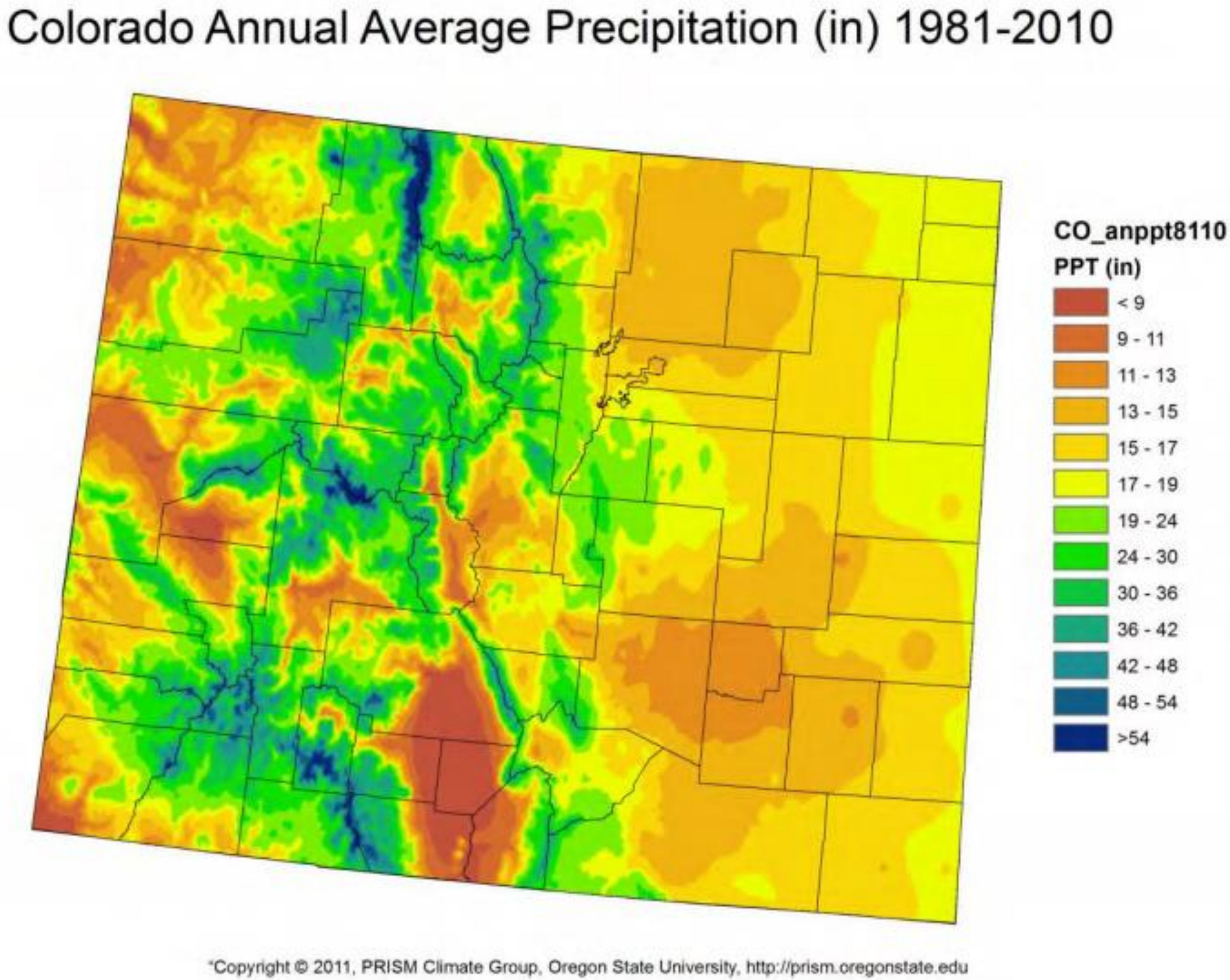
Example #1: Colorado

Major Colorado River Basin names



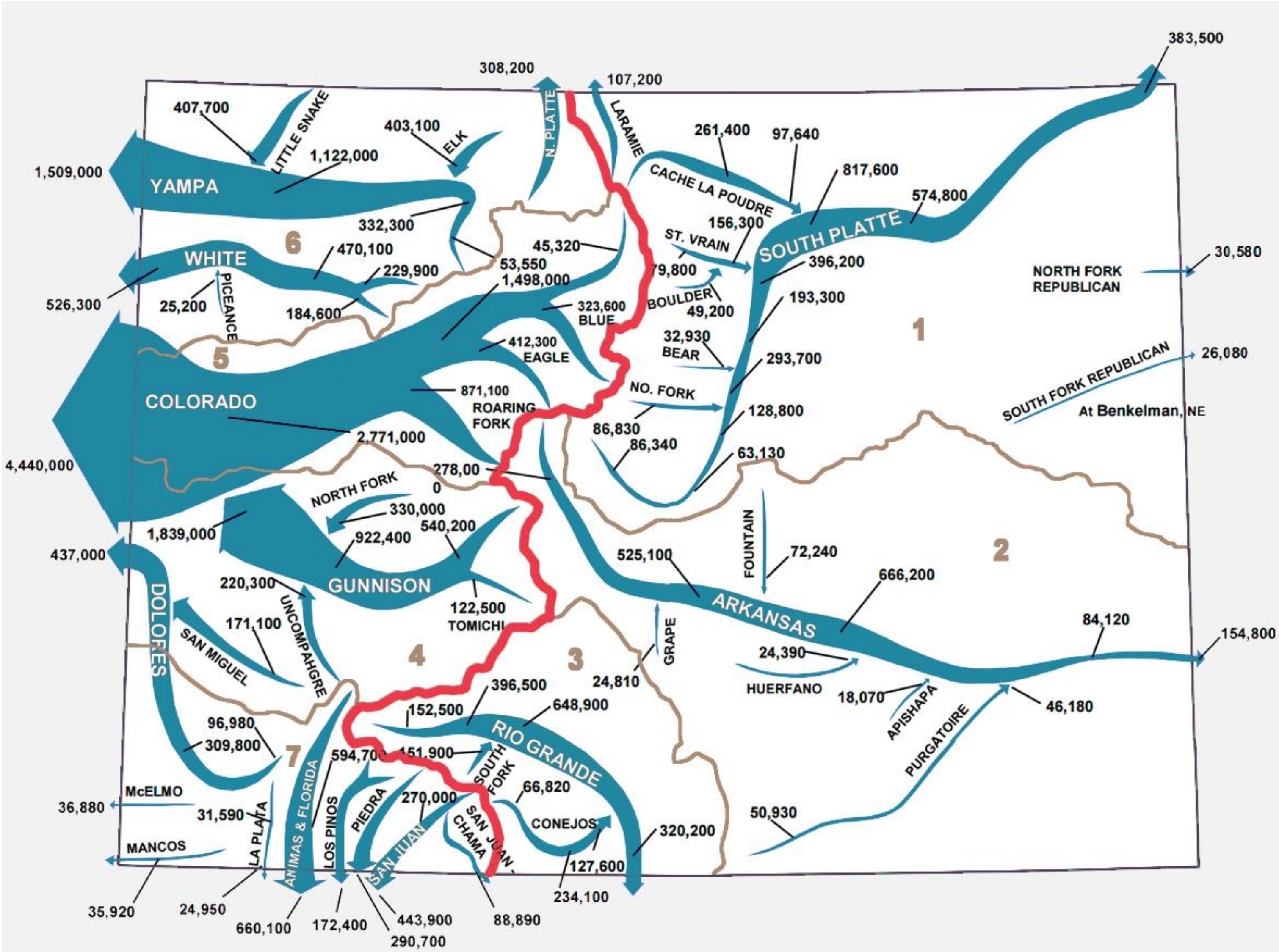
Percentage of Coloradans in each basin



Precipitation in Colorado. Note the dry pattern in the East. [Colorado Water Supply Plan 2014]

Historical Average Annual Colorado Stream Flows

West Toward Pacific Ocean 8,666,000 AF



East Toward Atlantic Ocean 1,331,000 AF

Total Leaving Colorado 9,997,000 AF

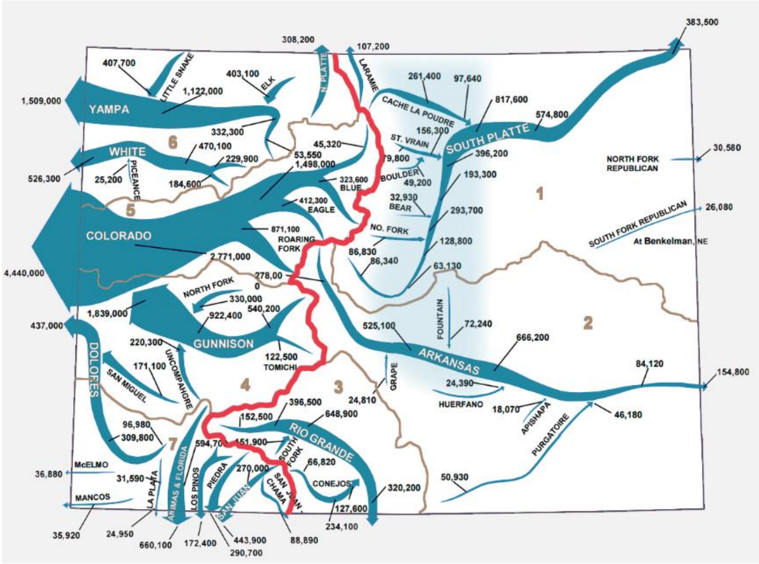
Courtesy Rebecca Smith

adapted from: Colorado Division of Water Resources

Front Range Water Challenges

Prior Appropriation, “first in time, first in right”

- water rights are property that can be bought, sold, and leased
- all rights are processed through water court
- many senior water rights are from agriculture



Population growth

- Front Range (Denver, Boulder, Colorado Springs) population projected to increase by up to 70% by 2050

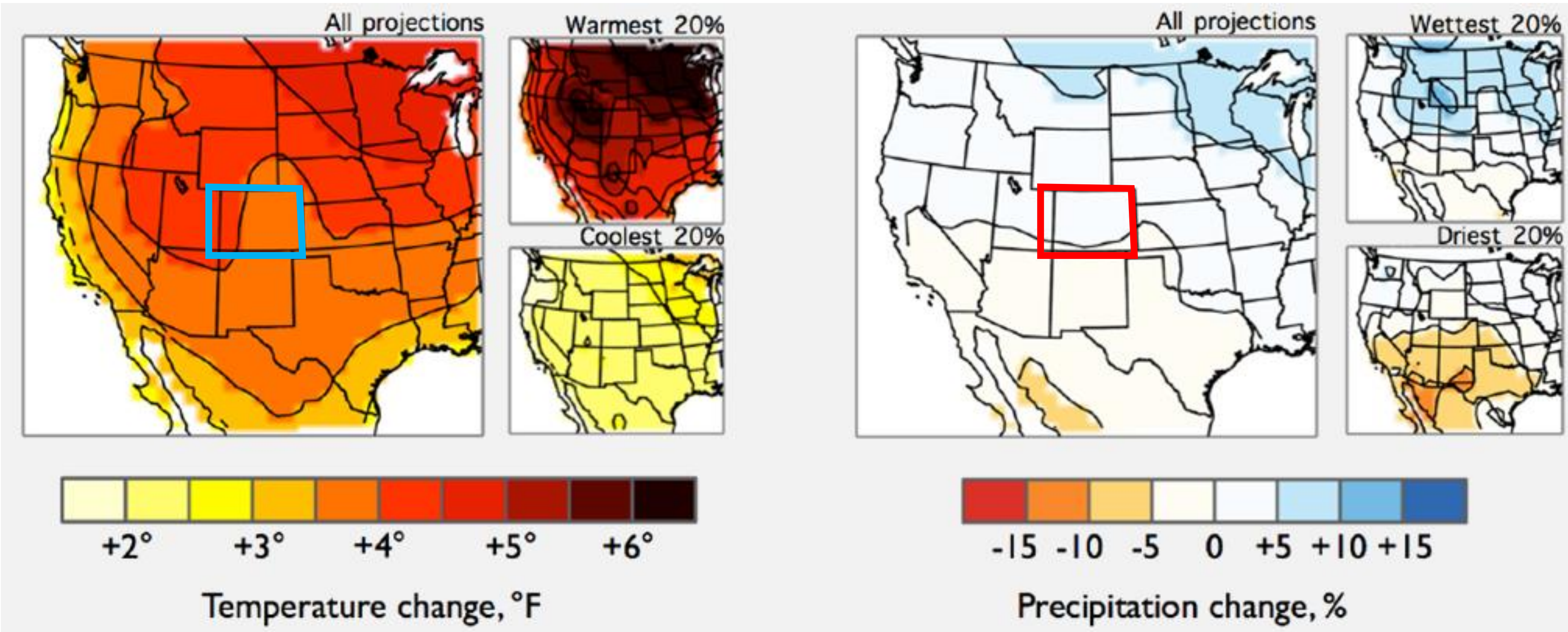
Tension between municipal, agricultural, and environmental demands

- pressure to increase conservation and reuse

Beetles, wild fires, and dust events impact critical snowmelt-driven watersheds

Courtesy Rebecca Smith

CMIP5: RCP 4.5 (medium-low emissions), 2050



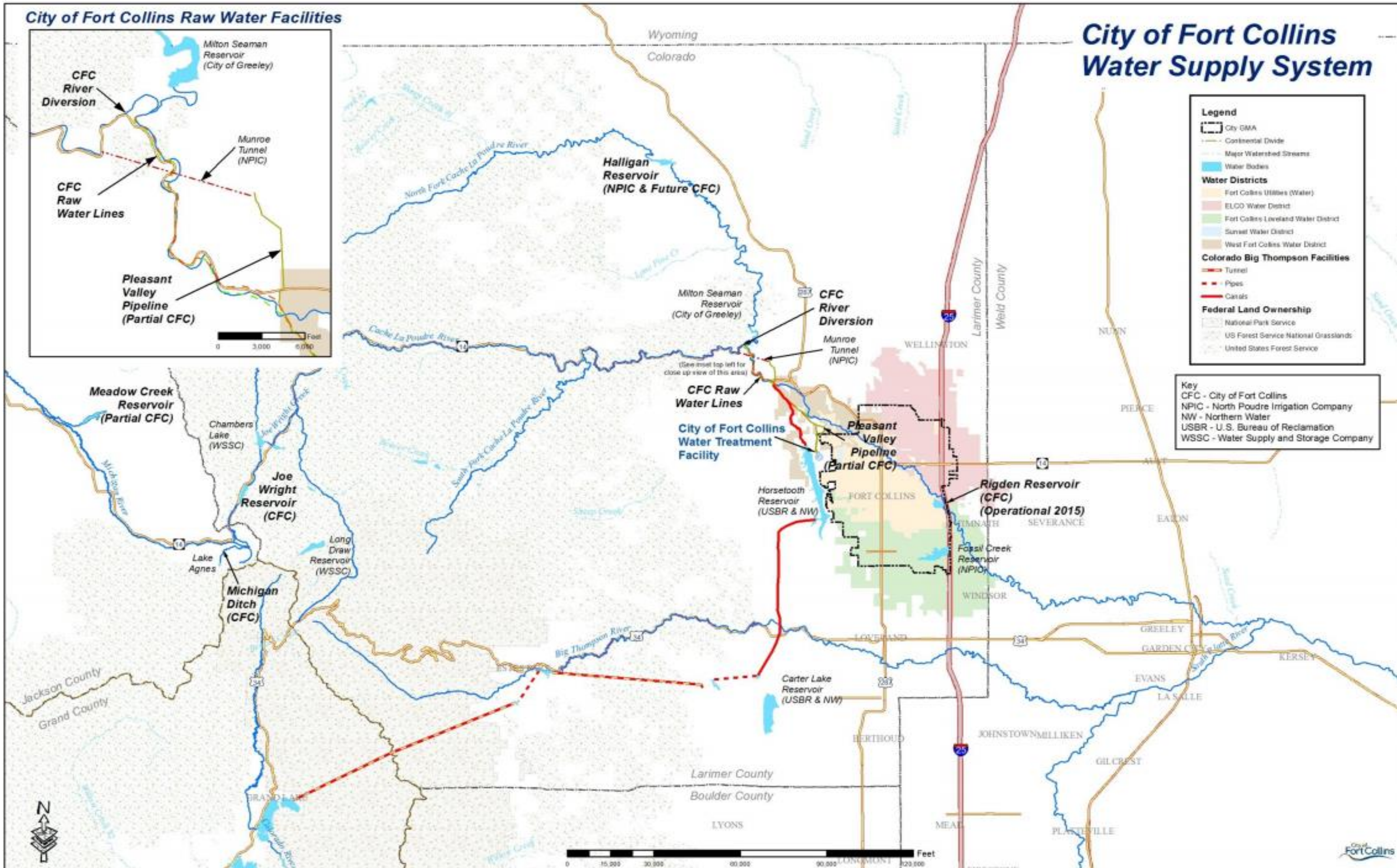
+2°F to +6°F by mid-century relative to 1971–2000

Precipitation impacts much less certain

Courtesy Rebecca Smith

source: WWA's Climate Change in Colorado (2014) Report

Example Front Range Utility: Fort Collins



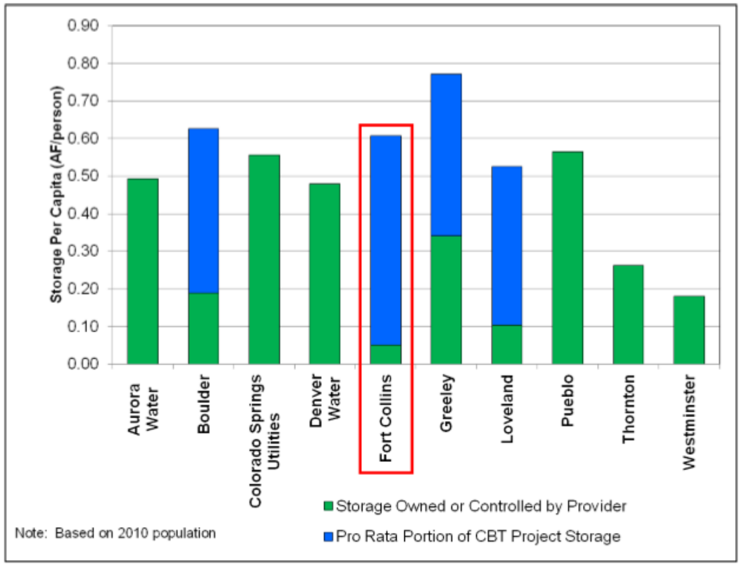
Courtesy William Raseman

Source: Fort Collins Water Supply and Demand Management Policy Revision Report, April 2014

Example Front Range Utility: Fort Collins

- Roughly 50/50 split between Poudre River and Horsetooth Reservoir[1]
- Horsetooth Reservoir
    - Mainly Colorado-Big Thompson Project (CBT) supplies which are subject to Federal regulations and potential Colorado River curtailment
    - Limited storage carry over from year to year
- Poudre River
    - Have sufficient water rights but no place to store the water
    - "…if the CBT supplies become unavailable for any reason, Fort Collins has very little storage in the Poudre River basin to respond to such an emergency" [Fort Collins Water Supply and Demand Management Policy Revision Report, April 2014]

Figure 23 Storage Per Capita



Source: Fort Collins Water Supply and Demand Management Policy Revision Report, April 2014

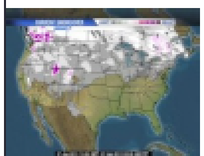
Courtesy William Raseman

RiverWare is a simulation model used for systems such as Fort Collins.

Hydrology Forecast

OR

Historic Record



OR

Stochastic Ensemble

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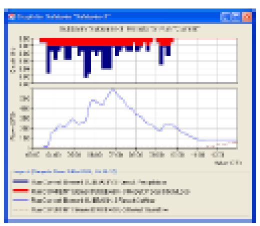

Rainfall – Runoff Model

Demands for Water and Energy

Operating Objectives and Constraints (policies)

IN

Models interaction of

Hydrologic response of River /Reservoir system (includes Hydropower)

With

Multi-objective operating policies

OUT

Values of Decision Variables, Performance Indicators

Schedule for Operations

Water accounting data

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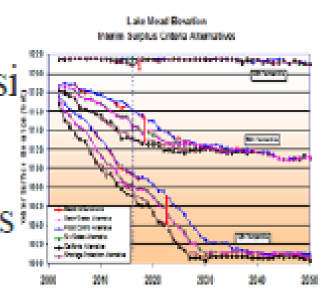
Export data to DSS, HDB, any DB

Export directly to Excel, Tableau, netCDF, GPAT

Statistical Analysis

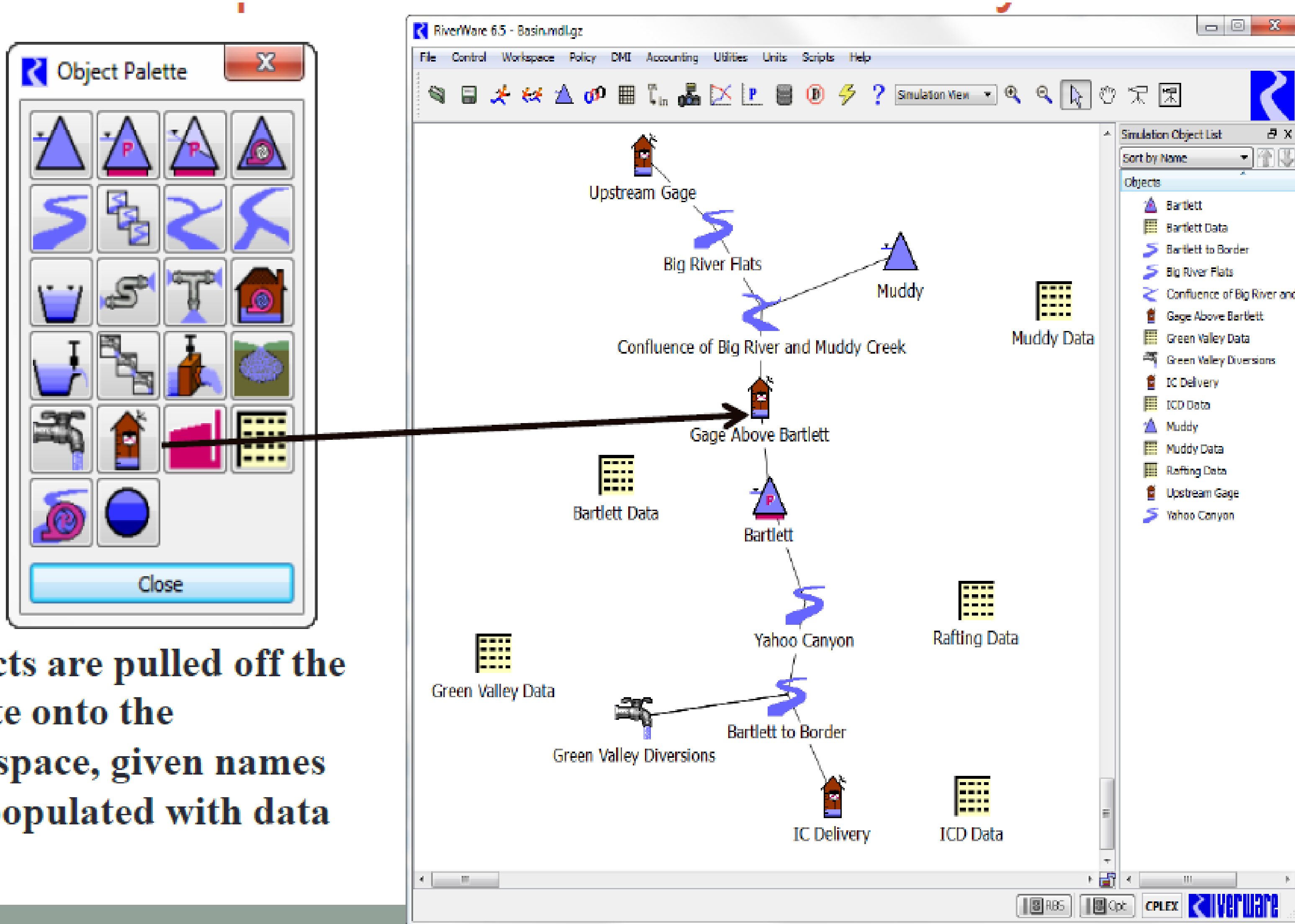
Policy Analysis

Tradeoff Analysis



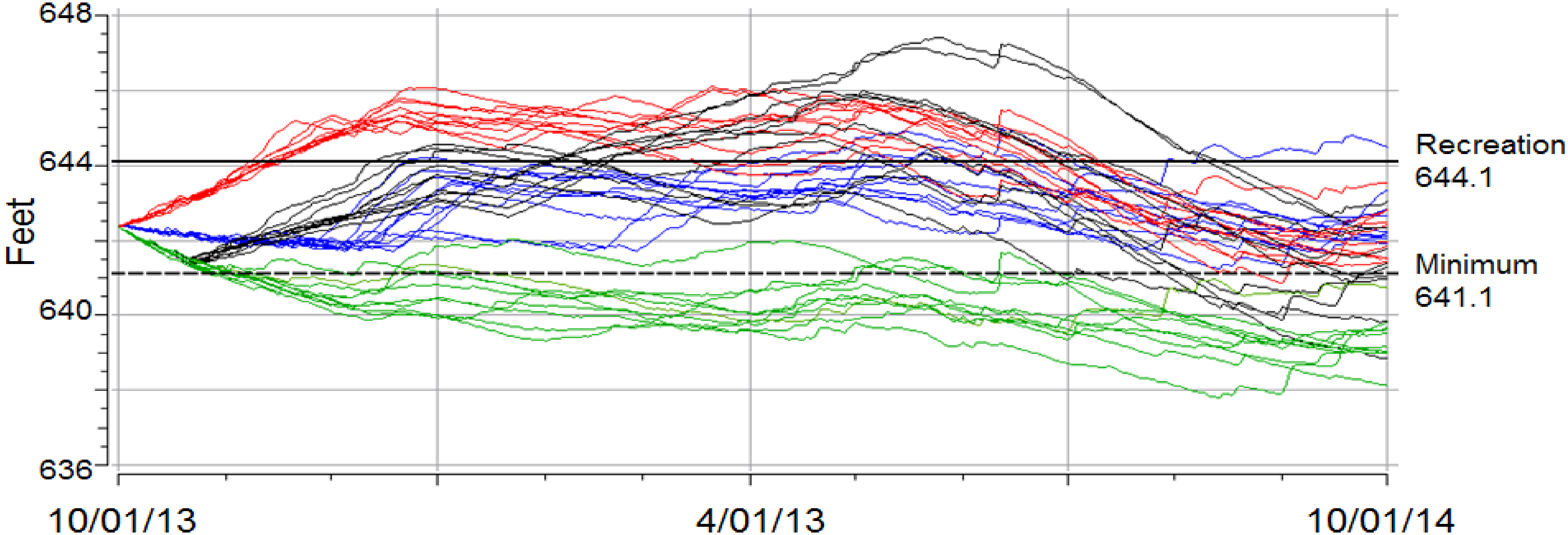
Courtesy Edith Zagona

An object-oriented interface represents the features of the system.



Objects are pulled off the palette onto the workspace, given names and populated with data

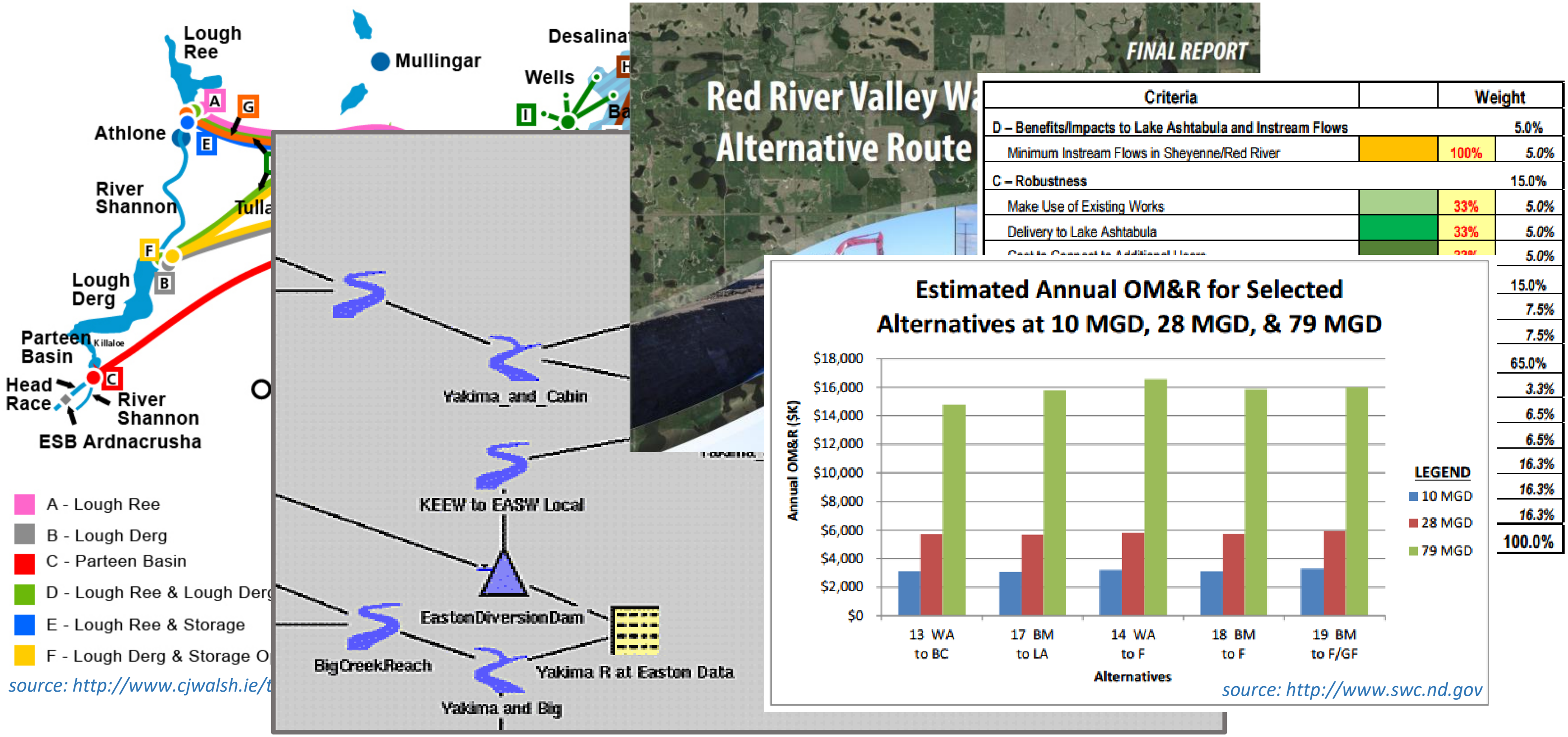
RiverWare can show the impact of reservoir operations on water storage trajectories.



Color shows three different management plans. Quantitative **performance objectives** can be used to judge the performance of these systems, such as reliability = the percentage of time that storage is above a particular target.

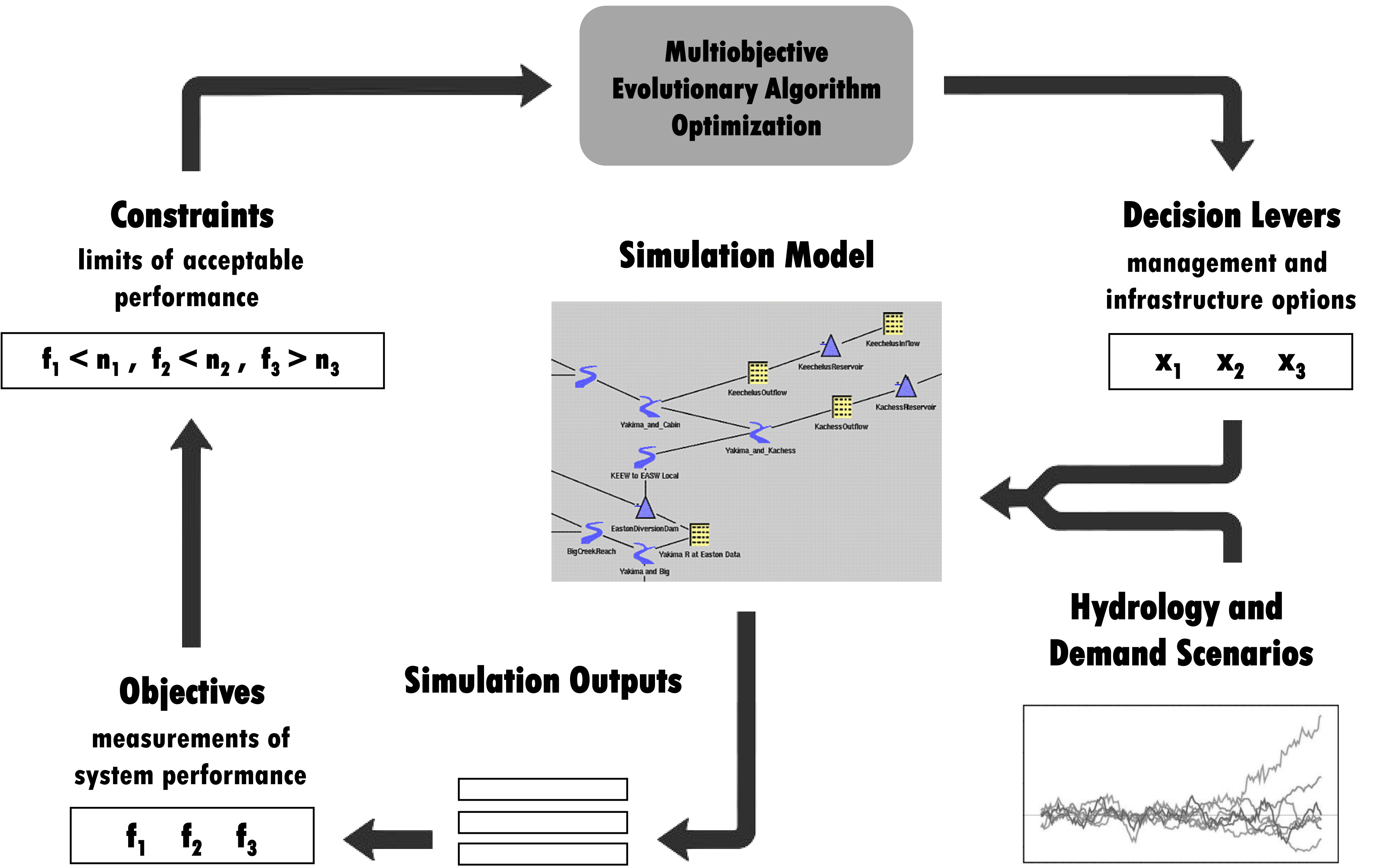
[Smith et al. 2016]

Traditional comparison of alternatives



How well can the system perform?

We need a better way to generate operation and infrastructure solutions.



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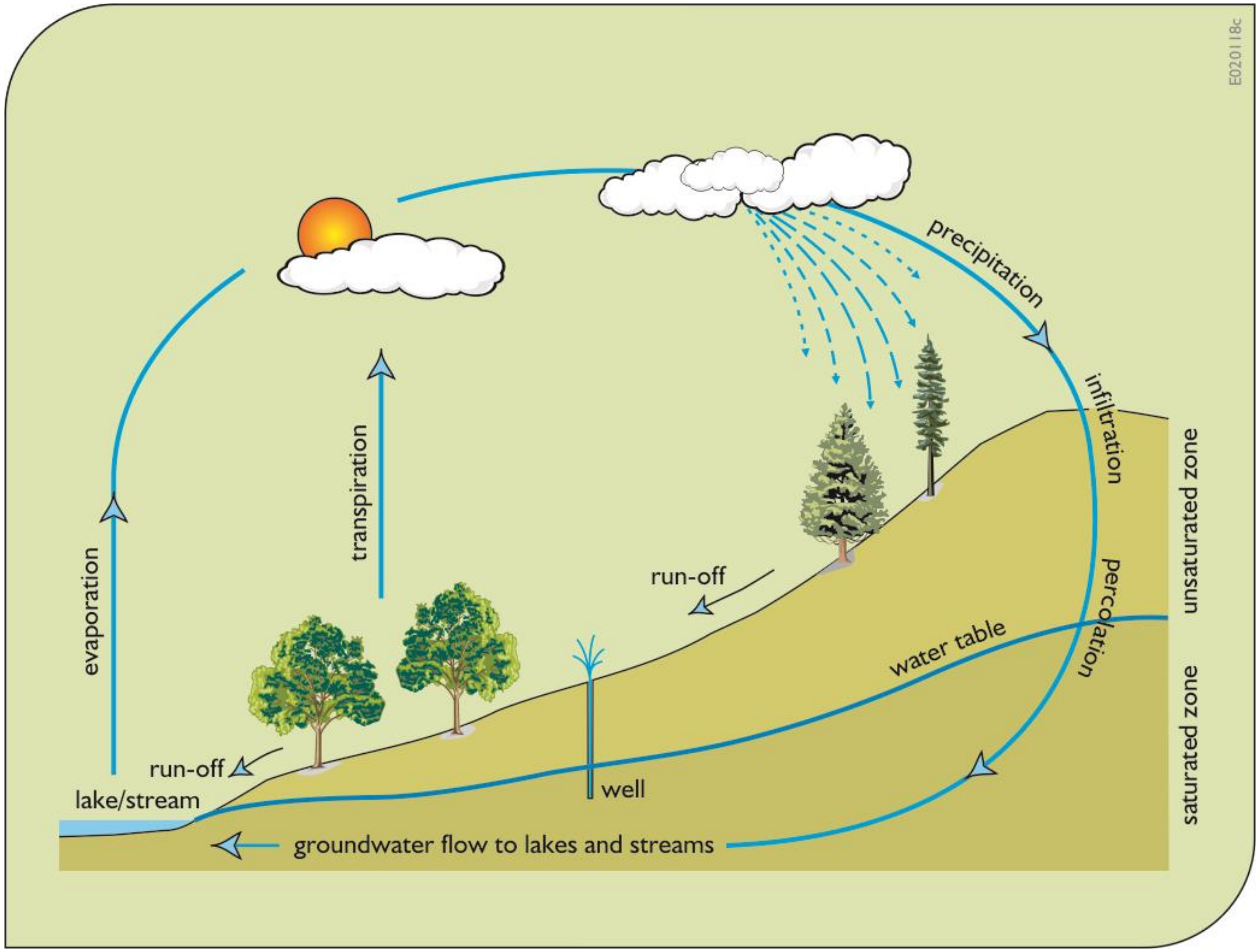
Hydrologic Cycle



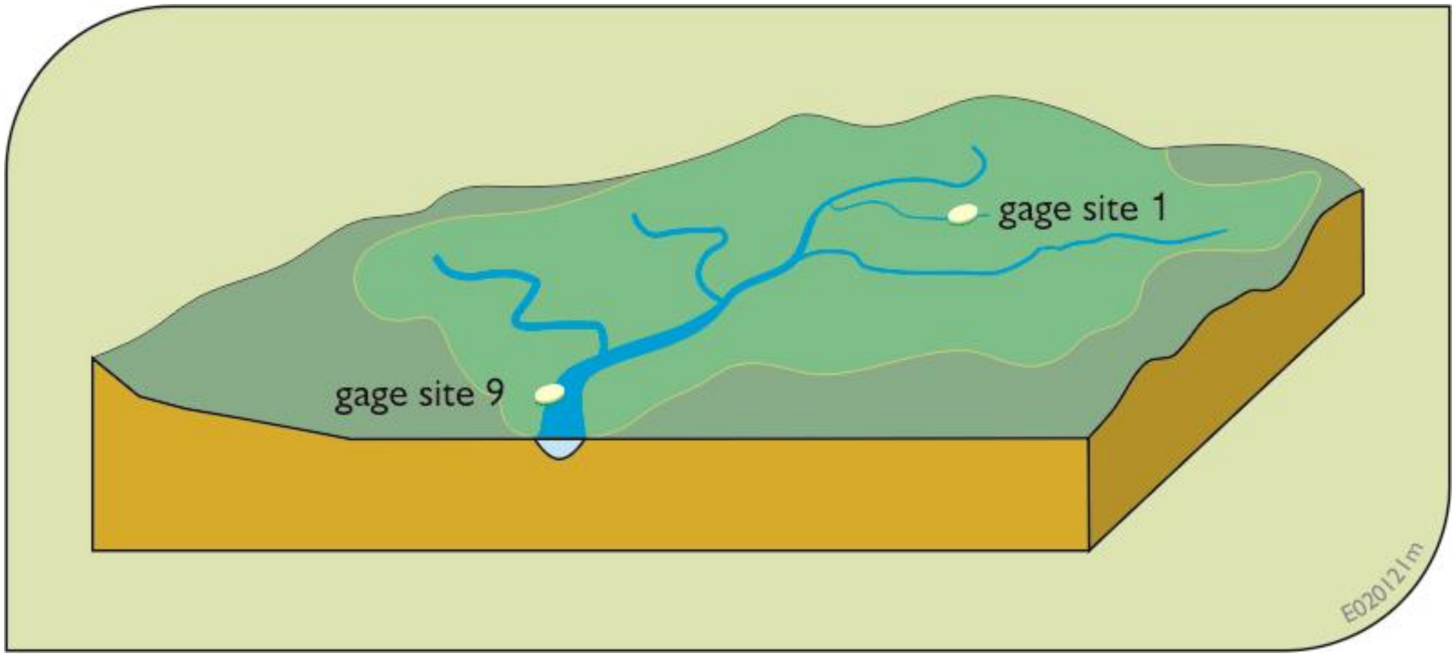
Discussion points:

- Measurement difficulties
- Process understanding
- Empirical vs. physically-based modeling
- Scale issues

Consult Ch. 11 in the Loucks and van Beek textbook for more information on hydrology from a water resource systems perspective.

In the CU Hydrology Water Resources and Environmental Fluid Mechanics program, we have:
5333 (Surface Water) Hydrology; 5363 Surface Water Modeling
5353 Groundwater Hydrology; 5383 Groundwater Modeling

Our friend the watershed (or the catchment, as the British say)



"That area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community" – John Wesley Powell

http://water.epa.gov/type/watersheds/whatis.cfm

A watershed is an area of land where all of the water that drains off of it goes into the same place.

Special considerations for river basin modeling for water resources applications

- The shortest period usually considered in **planning** analyses is one that is no less than the time water takes to flow from the upper to the lower end of the river basin.
    - For shorter duration time periods, **flow routing** may be required.
- Thus a weekly, monthly, or seasonal timestep may be used.
- See Ch. 11, Sec 1.2 for more discussion

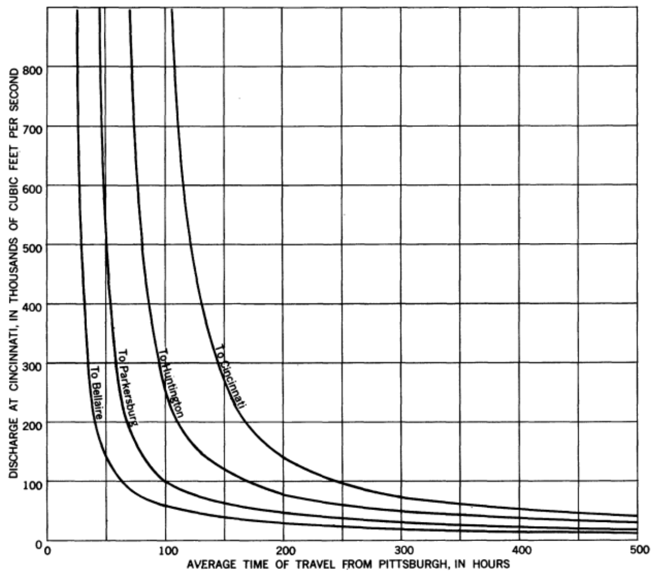


Figure 7.—Relation of discharge at Cincinnati, Ohio, to average time of travel of water from Pittsburgh, Pa., to selected downstream points.

Figure that shows the travel time on the Ohio River between Cincinnati and Pittsburgh on the Ohio River. [*http://pubs.er.usgs.gov/publication/cir439*](http://pubs.er.usgs.gov/publication/cir439)

Continuous rainfall-runoff models: HyMod

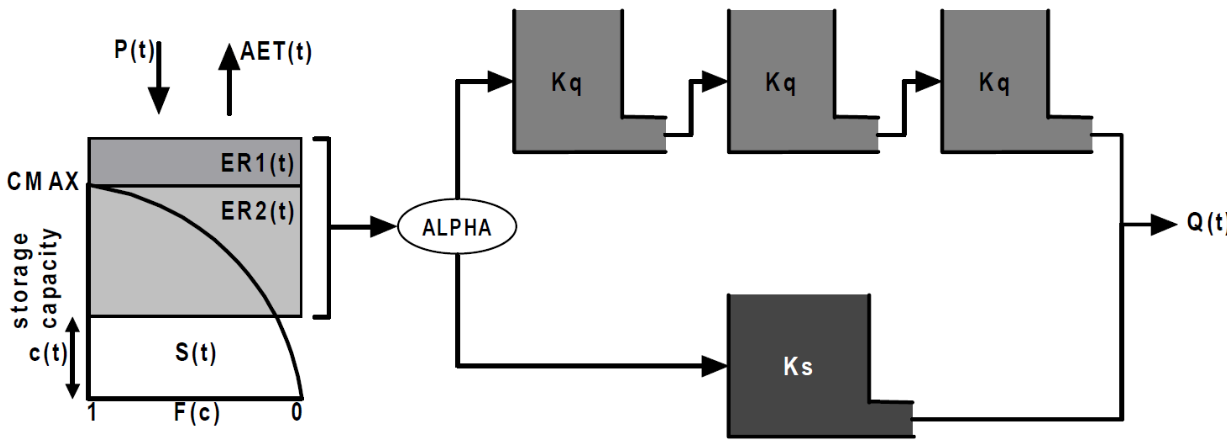


Fig. 4. *The model structure used in the rainfall-runoff modelling example. Effective rainfall (ER1(t) and ER2(t)) is produced depending on the current catchment moisture state described by the storage capacity distribution function F(c). The parameter CMAX describes the maximum storage capacity in the catchment. The effective rainfall is distributed with respect to parameter ALPHA and either routed through three linear reservoirs with residence time Kq in series, or a single reservoir with residence time Ks. Variable Q(t) is the resulting streamflow at time step t. The remaining variables are the storage S(t), the precipitation input P(t), and the actual evapotranspiration AET(t).*

<u>Parameters</u>

CMAX [L] the amount of soil moisture storage capacity, range: 0-500

BEXP [-] variability of soil moisture capacity, range: 0-2

ALPHA [-] split between the quick and slow flow reservoirs, range: 0-1

Kq [T] residence time of quick flow reservoir, range 0.1-1.0

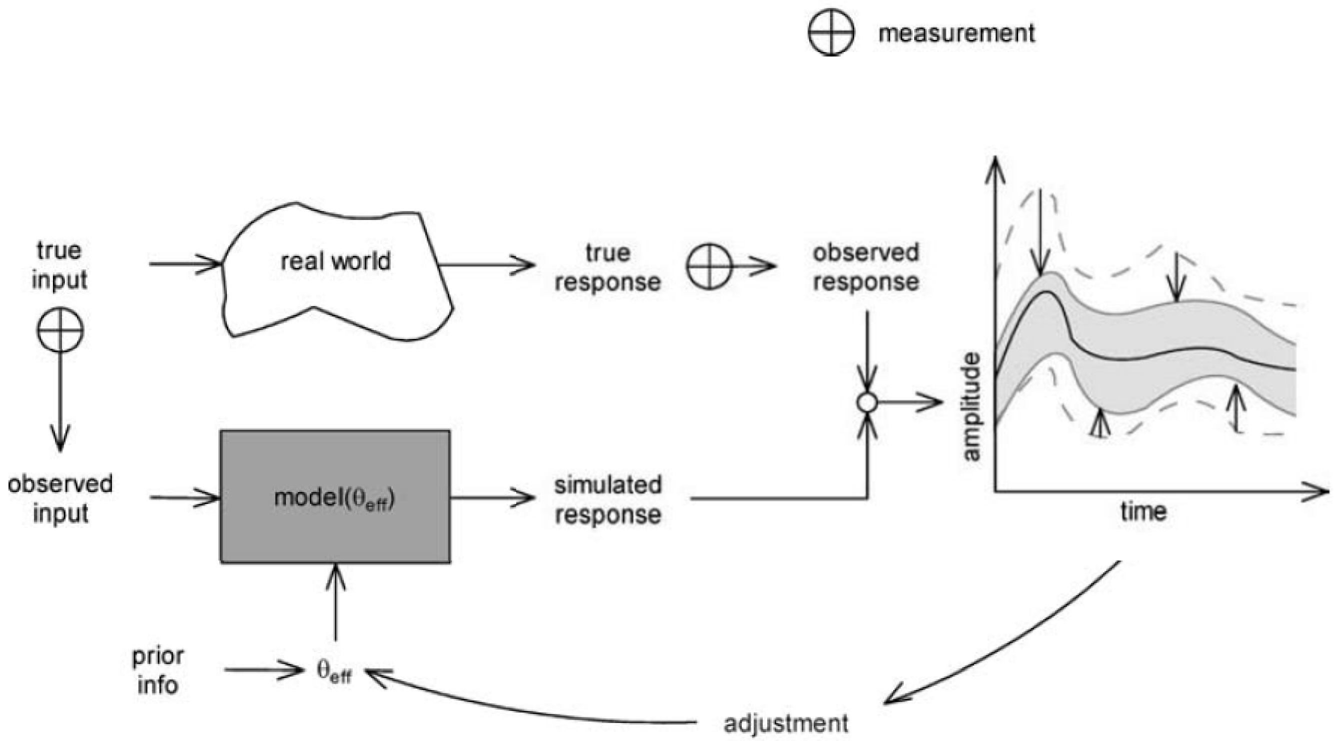
Ks [T] residence time of slow flow reservoir, range 0-0.1

Brackets indicate the units (L=length; T=time; a dash indicates no units)

Setting up the HyMod model

- Inputs
  - Daily Precipitation
  - Daily estimates of Potential Evapotranspiration
- Outputs
  - Streamflow
  - The model also contains **state variables** such as soil moisture that can be observed
- Validation Data
  - **Observed** streamflow which shows what “actually” happened in the catchment

Parameter estimation

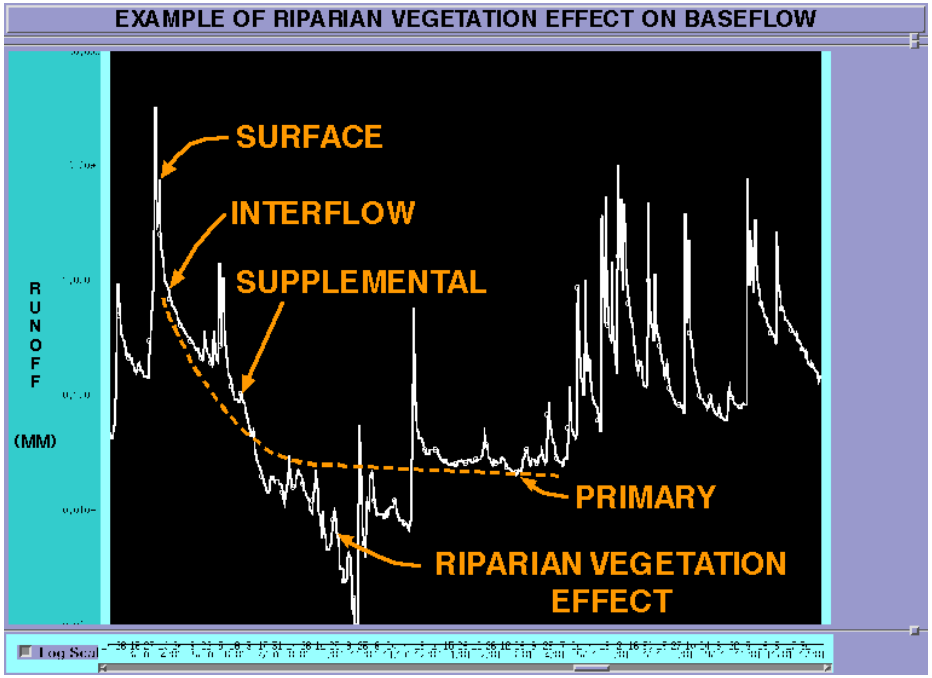


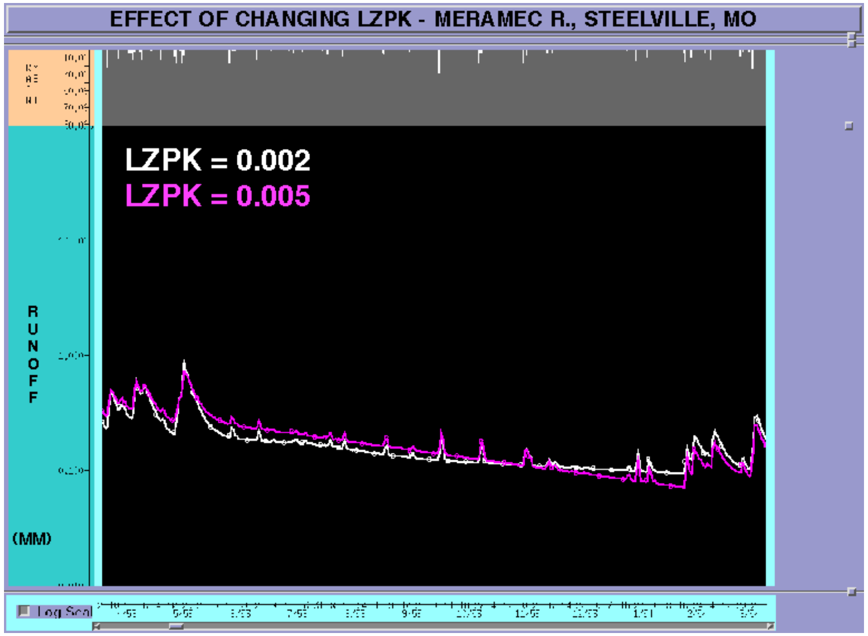
Comparing the **simulated response** to the **observed response** allows us to adjust **model parameters** (θ_{eff})

[Wagner and Gupta, 2005]

Manual Calibration

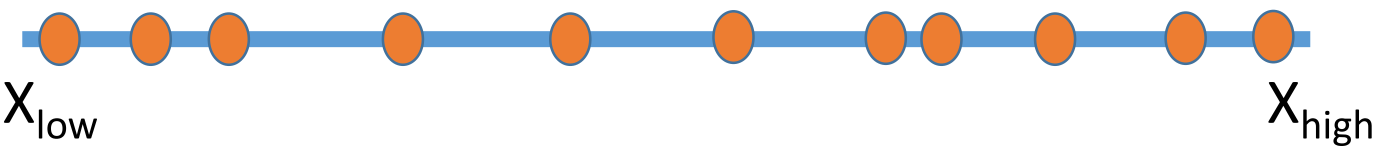
- A hydrologists adjusts parameters of the model by hand, observes the fit, and changes the parameters to improve the fit
- Figures from National Weather Service webpage (http://www.nws.noaa.gov/oh/hrl/hsmb/hydrology/calibration/training_Mar1998.html)



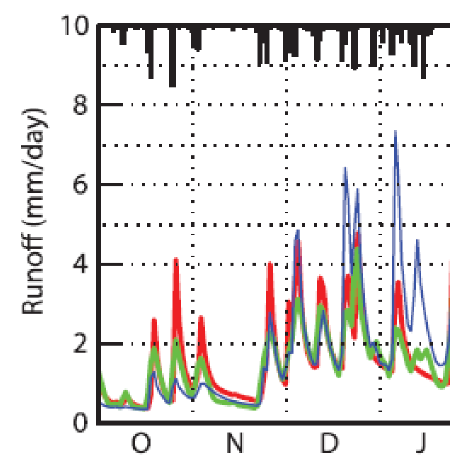


Sampling the parameter space

- Consider a parameter, X, with a lower bound X_{low} and an upper bound X_{high}. We can use a random number generator to sample from this range:

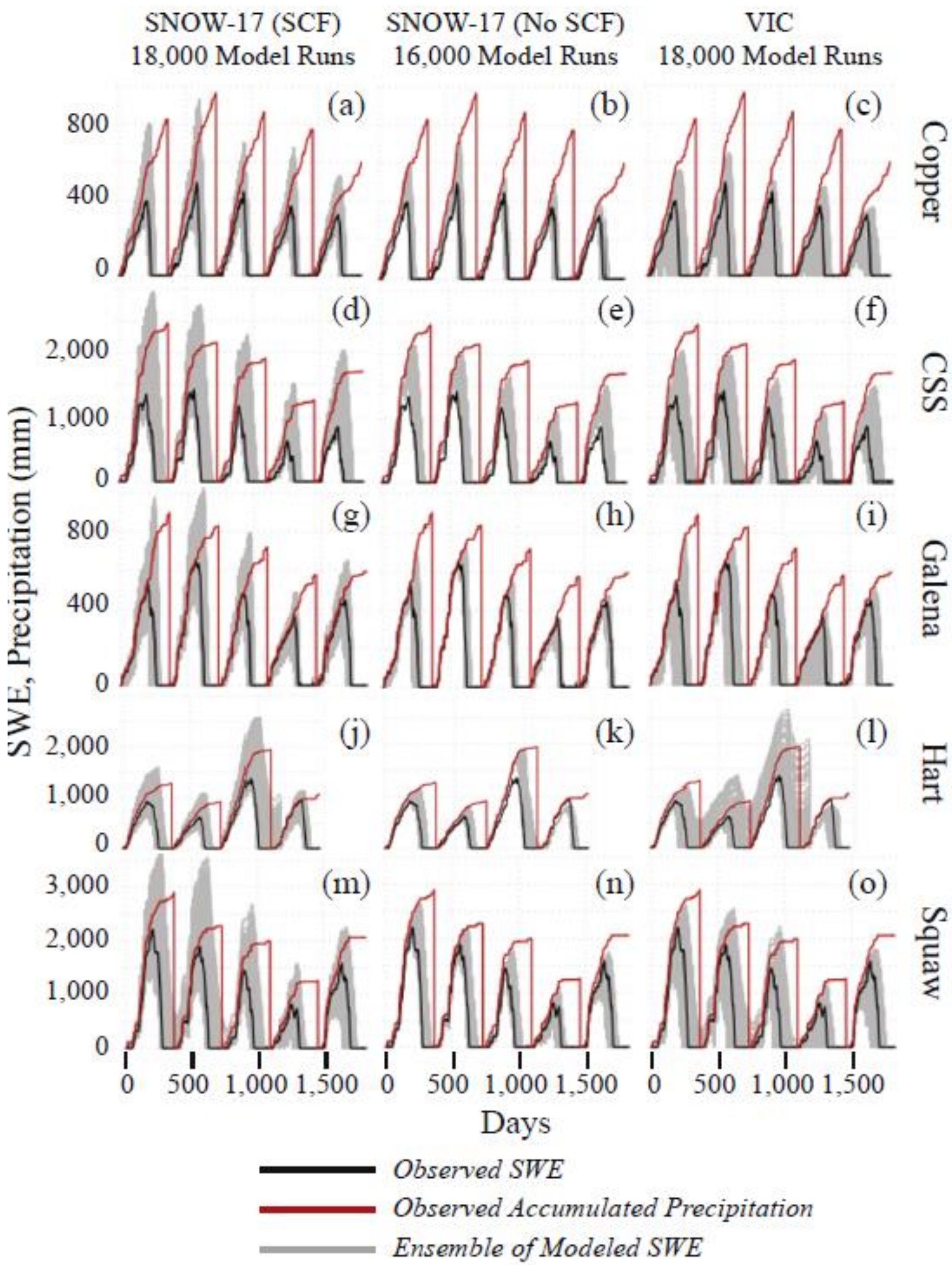


- Each sample is a unique set of parameter values
- Using HyMod as an example:
  - Sample 1: CMAX = 20; B = 1; Alpha = 0.5; Kq = 0.5; Ks = 0.05
  - Sample 2: CMAX = 50; B = 1.5; Alpha – 0.2; Kq = 0.9; Ks = 0.06
- Run a model using each sample, and calculate the simulation's fit with respect to the observed data (see figure)

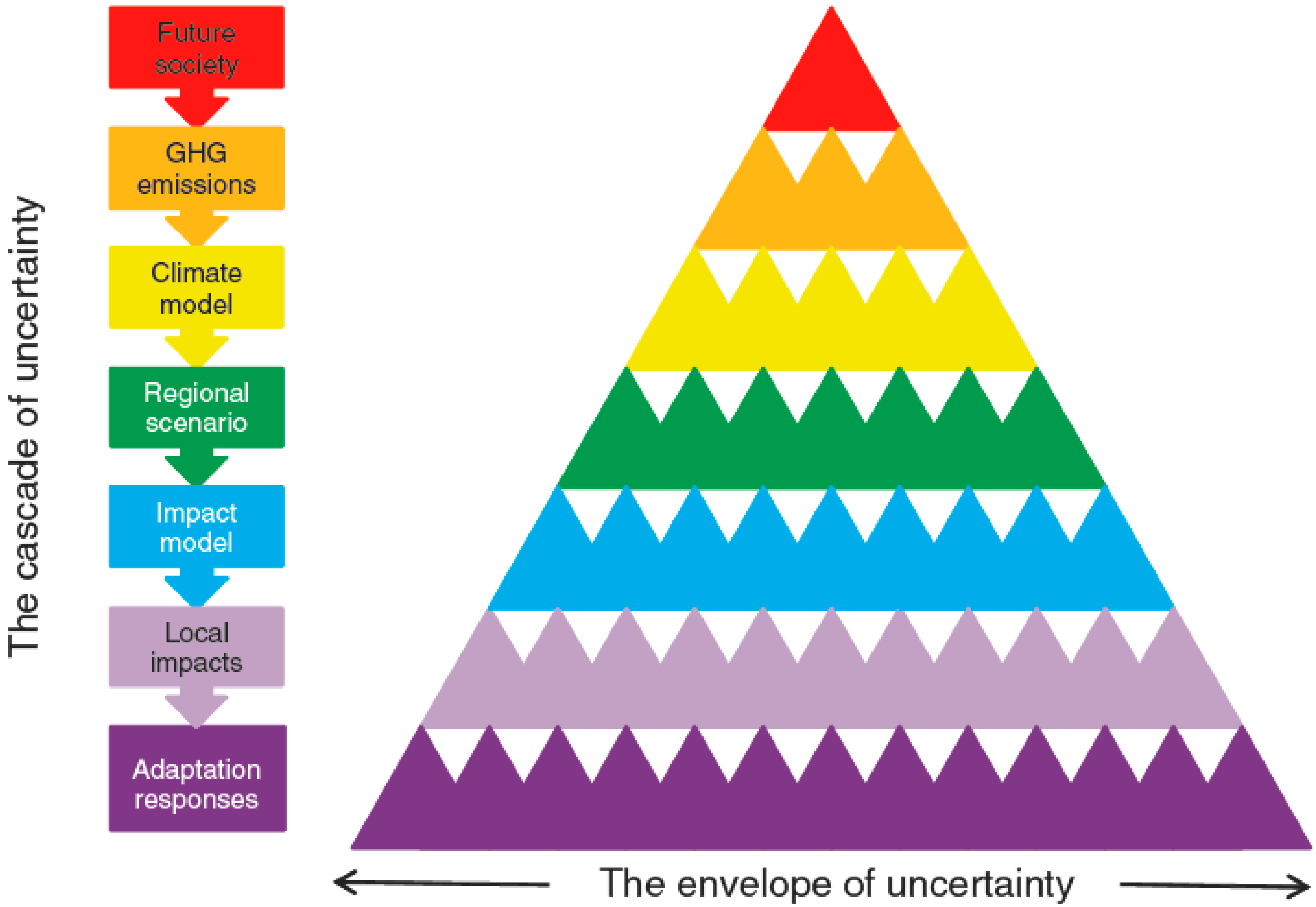


Parameter uncertainty example: Snow modeling

Comparing two snow models (columns) across different sites (rows). The snow correction factor (SCF) within SNOW-17 is shown to be important in helping constrain the model to have realistic results. We also show situations where models consistently over or underpredict snow water equivalent (SWE) *[Houle et al 2017]*

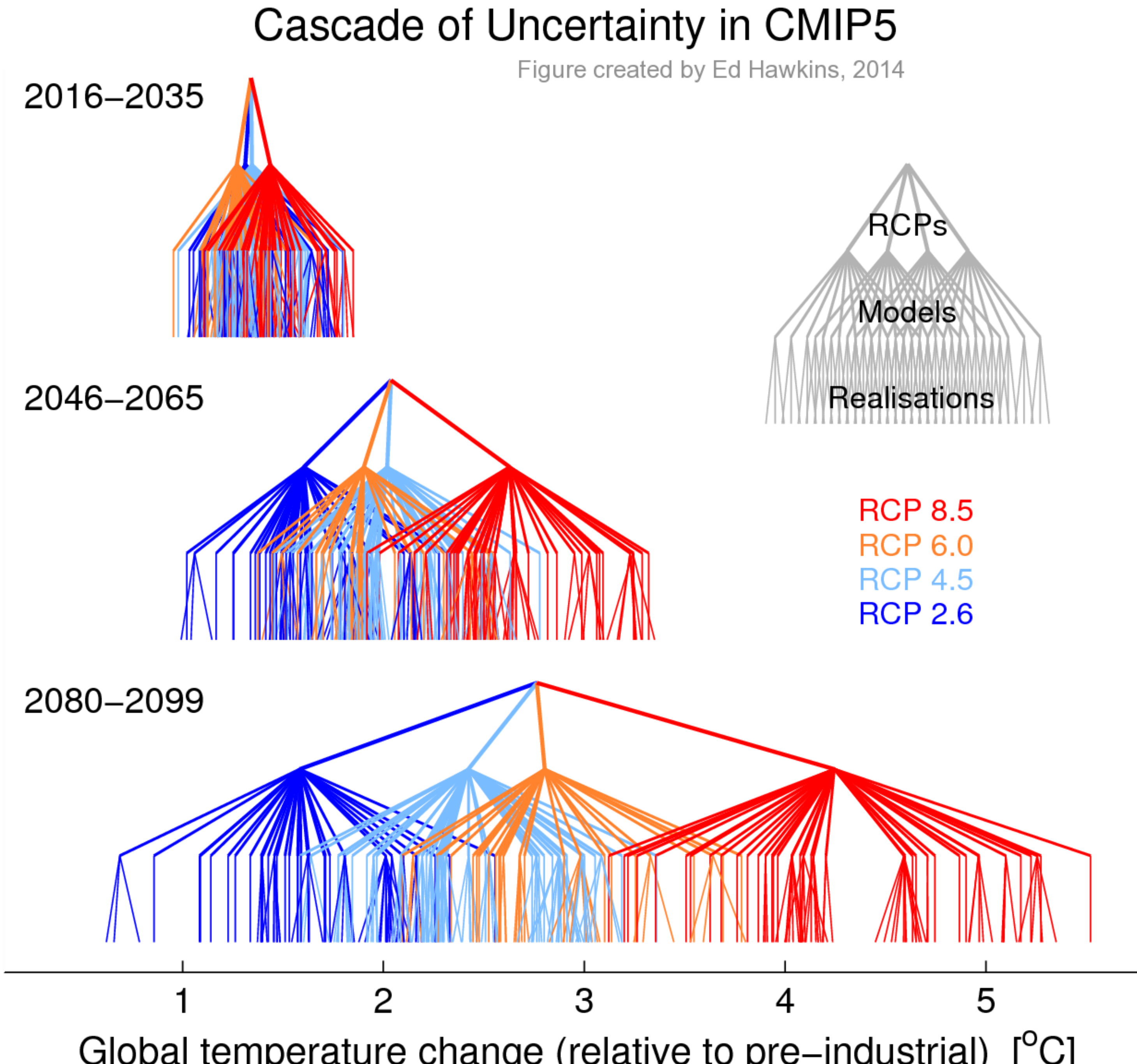


One important use of scenarios within modeling is for climate change assessment…



http://www.climate-lab-book.ac.uk/2014/cascade-of-uncertainty/

The ‘cascade of uncertainty’ in global mean surface temperature from the CMIP5 simulations for different time periods as labelled. The three levels of the pyramid highlight the uncertainty due to the choice of RCP, GCMs and realisation of climate variability. Unfortunately not all the simulations have multiple realisations, resulting in a vertical line in the lowest layer. The intersection on the top row for each time period is the multi-scenario, multi-model, multi-realisation mean.



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A model like HyMod is one part of this schematic…

Hydrology

Forecast

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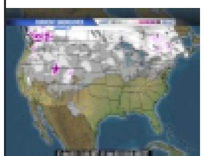

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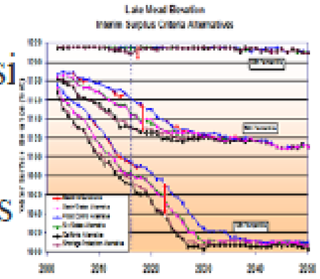

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